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Air quality modelling

Albert Soret Miravet
Earth Sciences Department at BSC



Objective: to introduce air quality and climate modelling systems to explore their potential applications at urban scales.

Outline:

- Introduction to:
 - BSC activities
- Air quality
 - Urban areas
 - Air quality in Europe
 - Case studies
- Future work

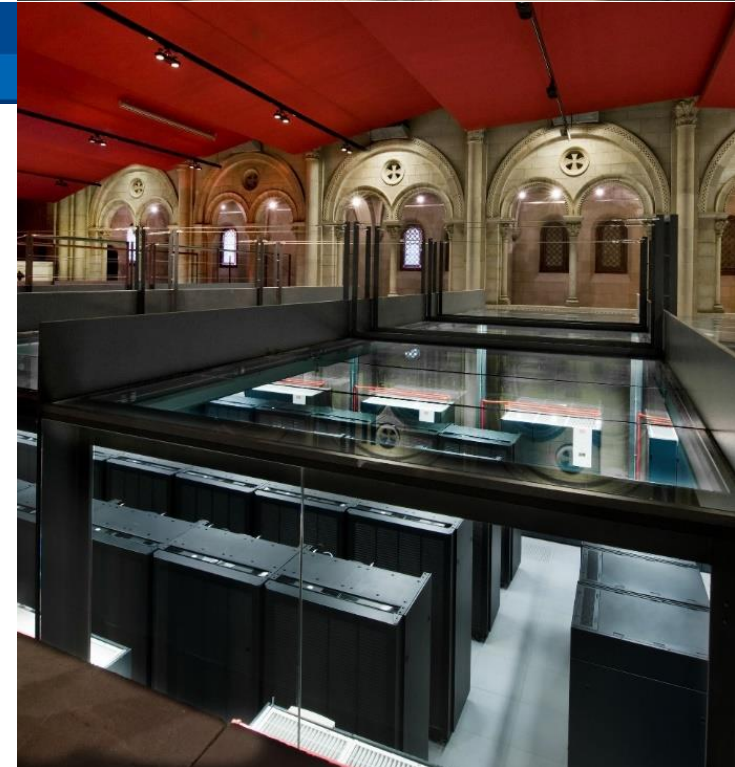


Introduction

- Created in 2005; 350 employees
- Research, develop and manage information technology
- Facilitate scientific progress and its application in society

Earth Science Department

- Atmospheric composition modelling
- Climate prediction modelling
- Computational Earth Sciences
- Earth Sciences Services

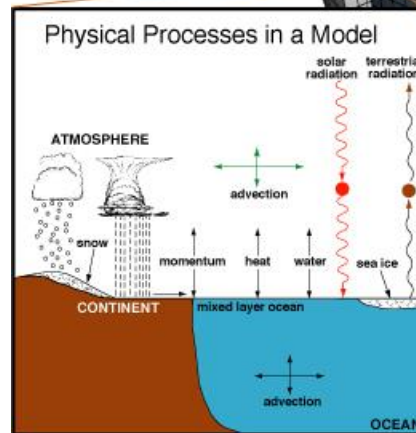
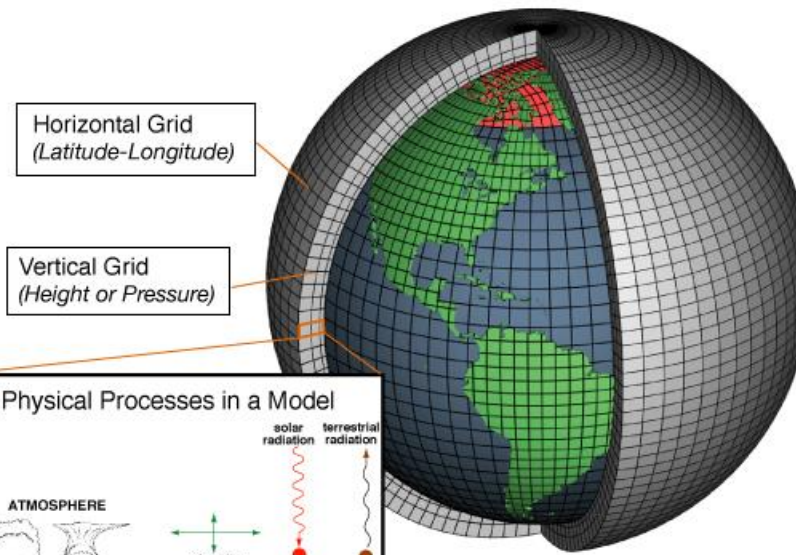


Earth sciences modelling: climate and air quality modelling

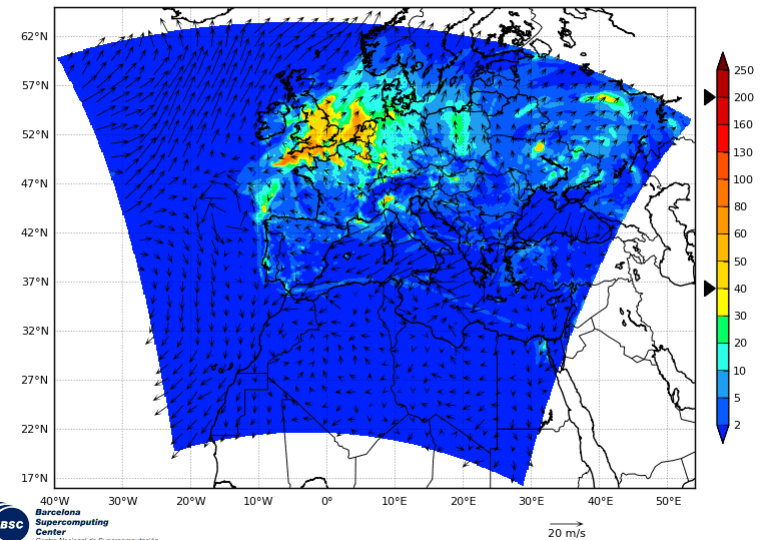


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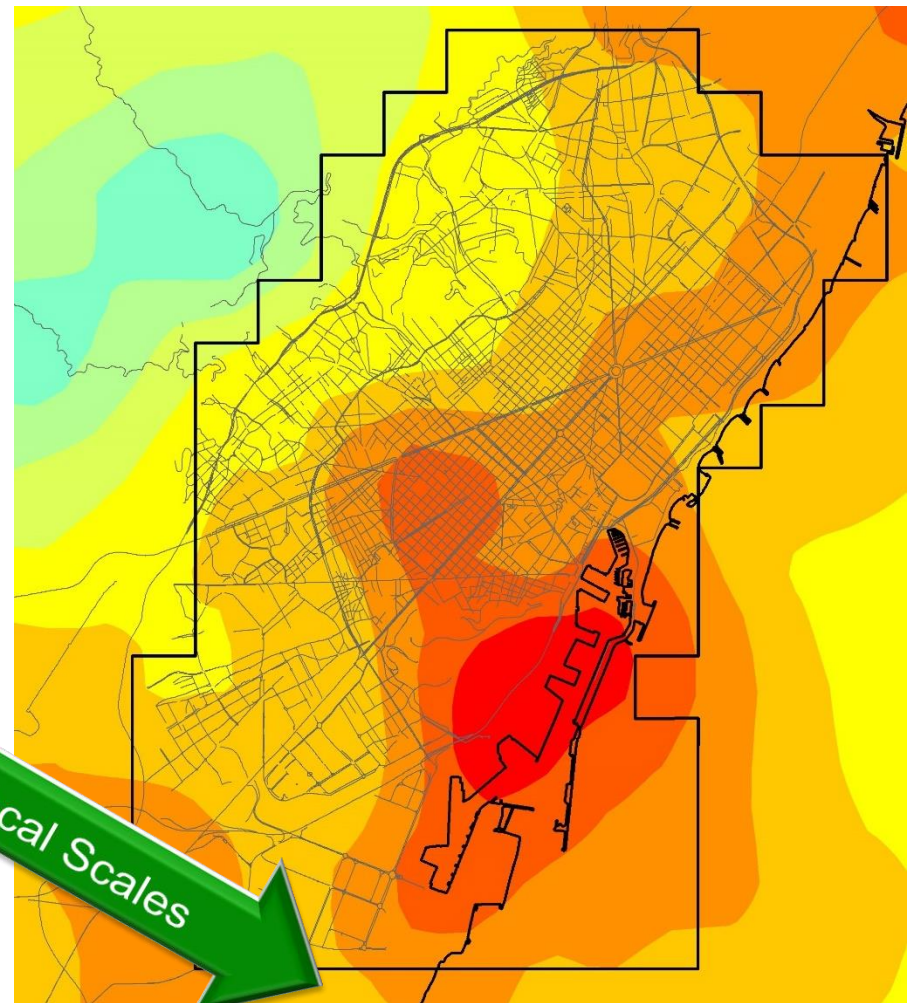
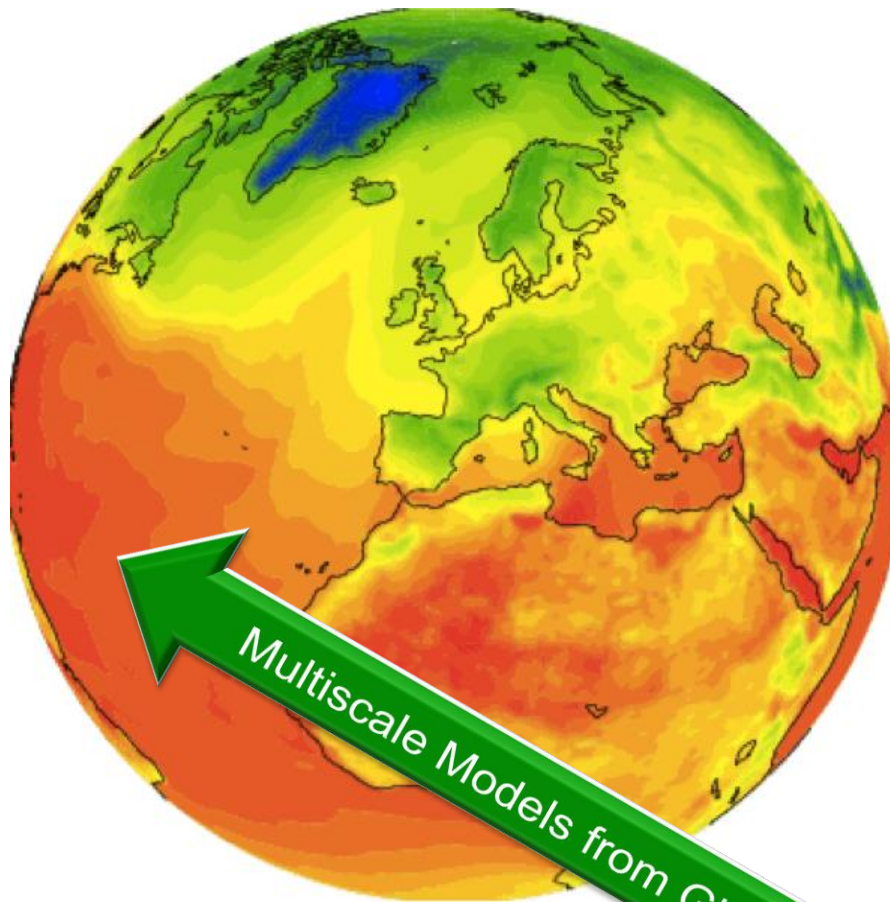
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BSC-ES/AQF WRFv3.5.1+CMAQv5.0.2+HERMESv2 Nitrogen Dioxide ($\mu\text{g}/\text{m}^3$)
00h forecast for 00UTC 01 Nov 2015 - Europe Res: 12x12km

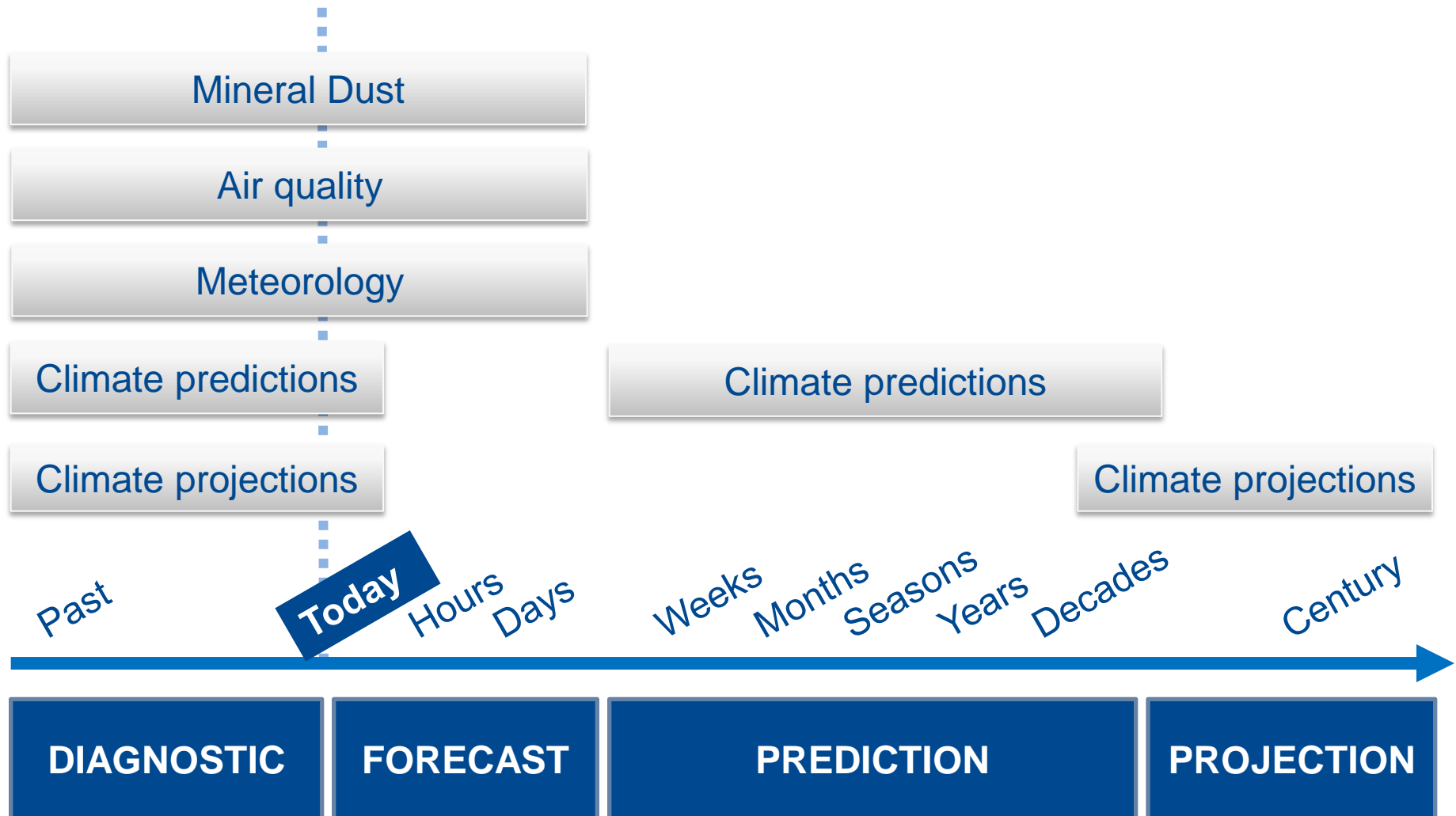


Multi-scale models from global to local scales



Multiscale Models from Global to Local Scales

Temporal scales

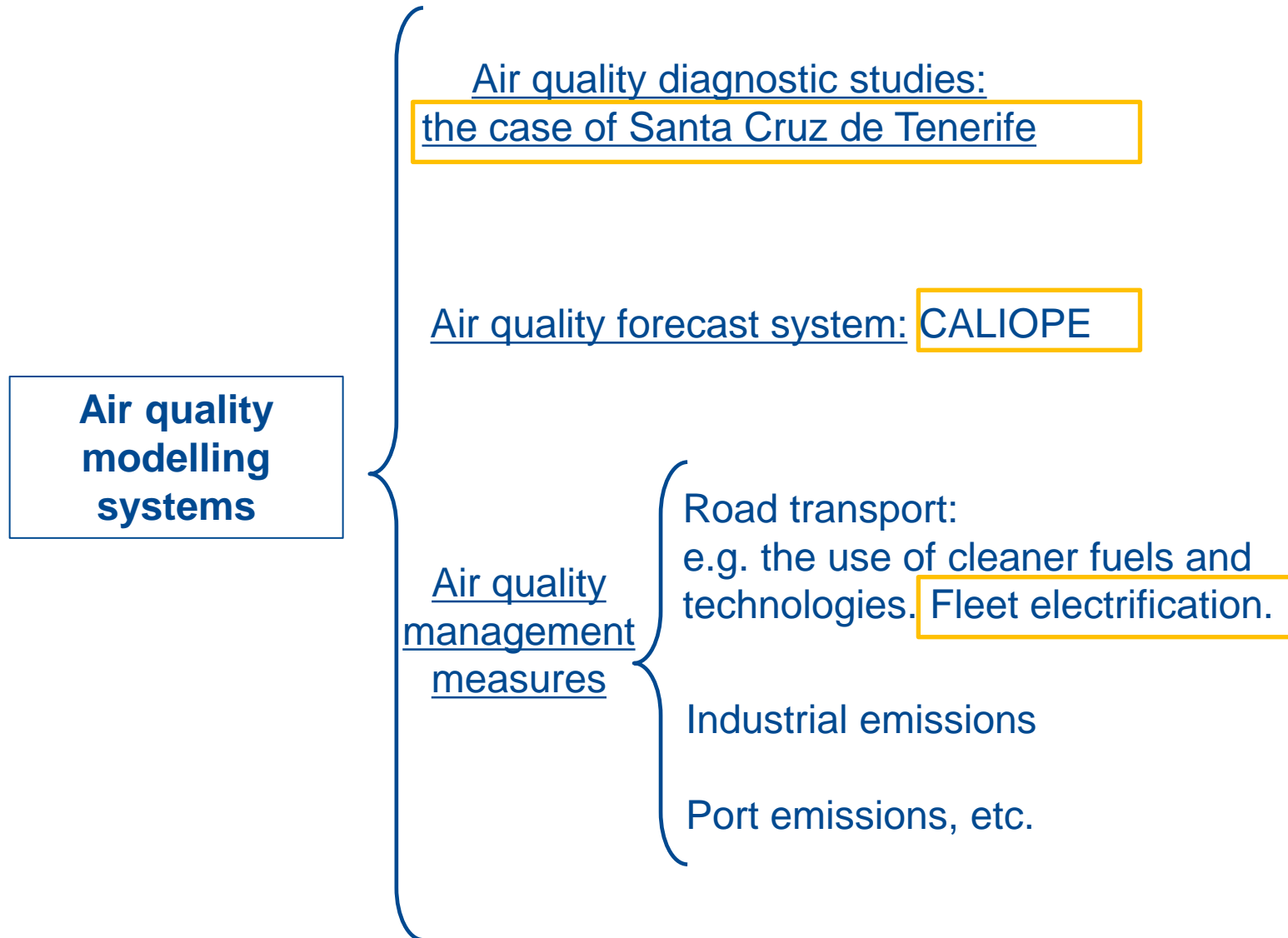


Air quality and climate modelling systems in urban areas. Framework at BSC



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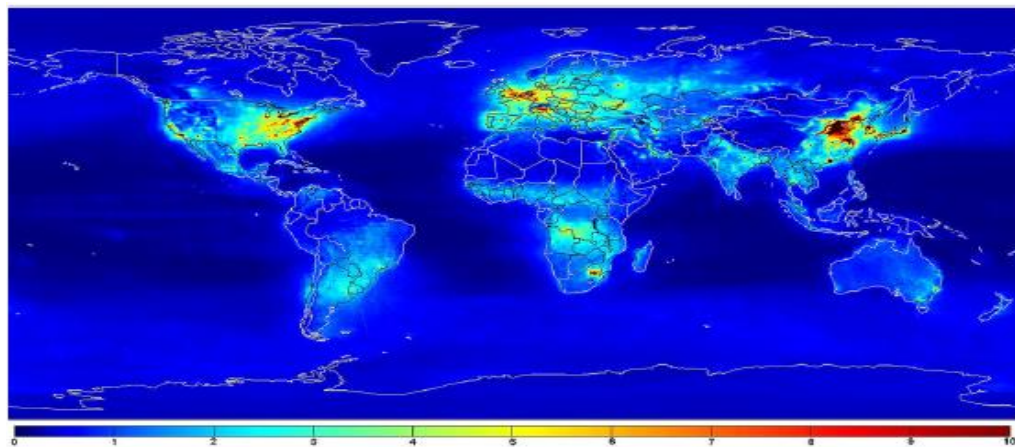
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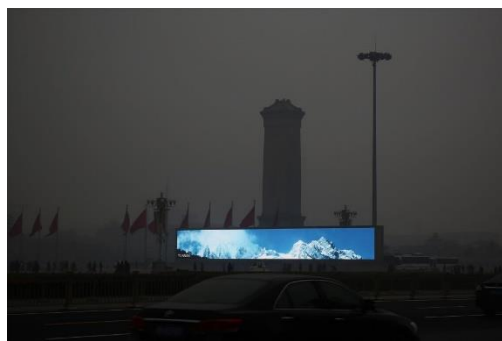


Air quality

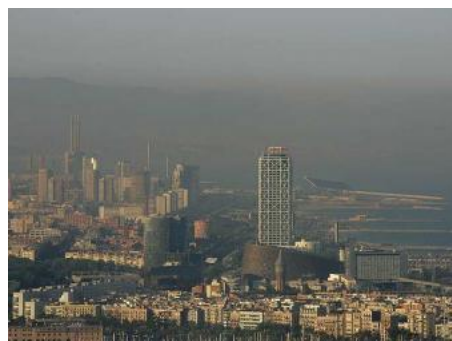
Air pollution in urban areas



OMI tropospheric NO₂ vertical column densities, 2005 average (1015 molecules/cm²) (Wenig et al., 2008).



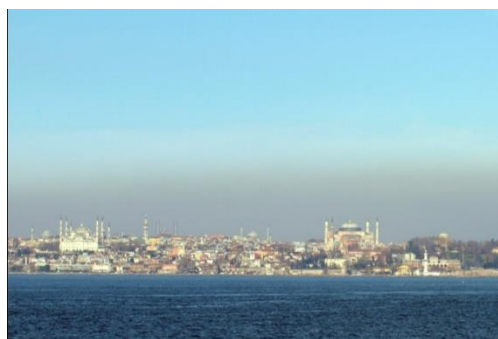
Beijing



Barcelona



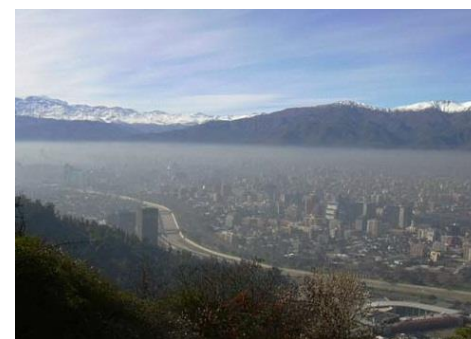
Madrid



Istanbul



Mexico DF



Santiago de Chile

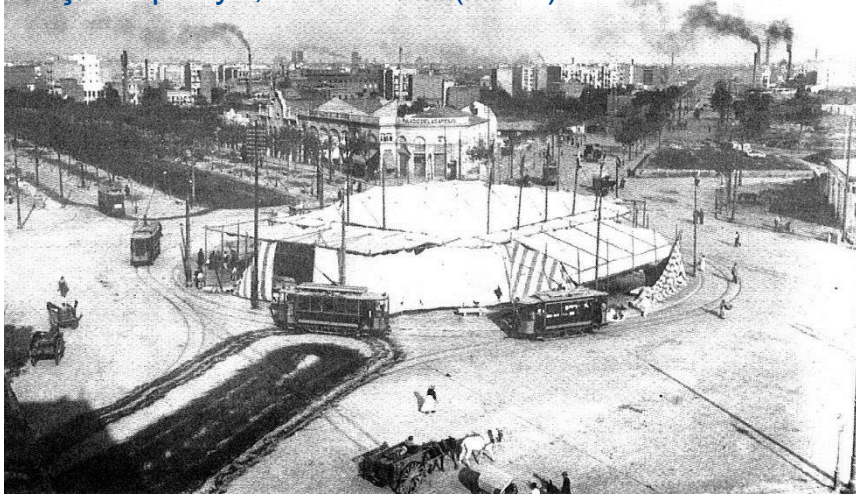
Air pollution and urban areas: causes



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Plaça Espanya, Barcelona (1908)



Plaça Espanya, Barcelona (2014)



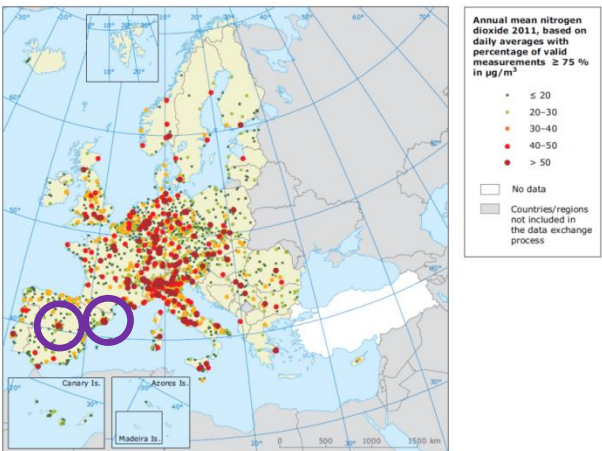
C/ Gran de Gràcia, Barcelona (1908)



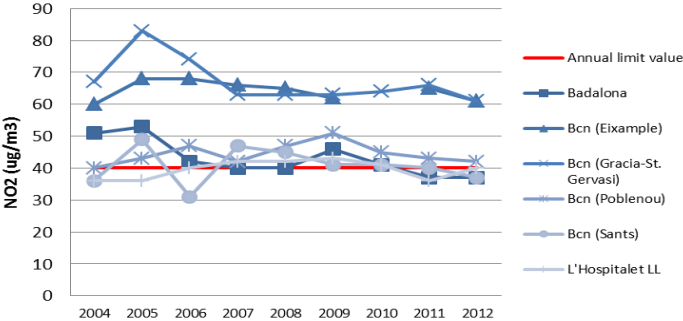
C/ Gran de Gràcia, Barcelona (2014)



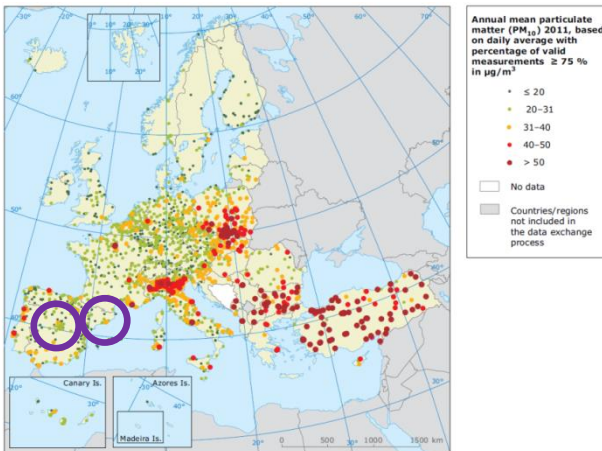
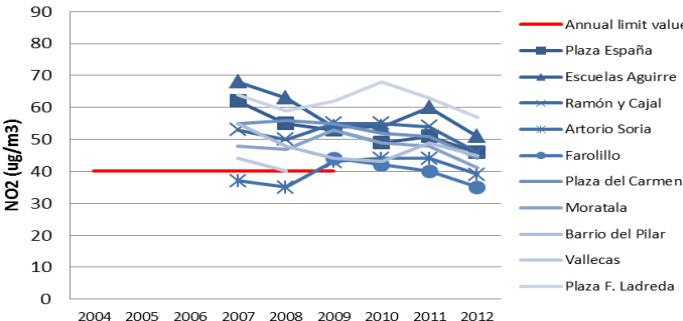
Air pollution in Europe



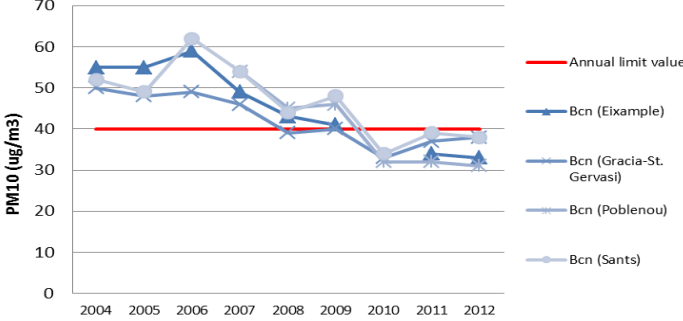
Barcelona NO₂ trends; yearly average concentration



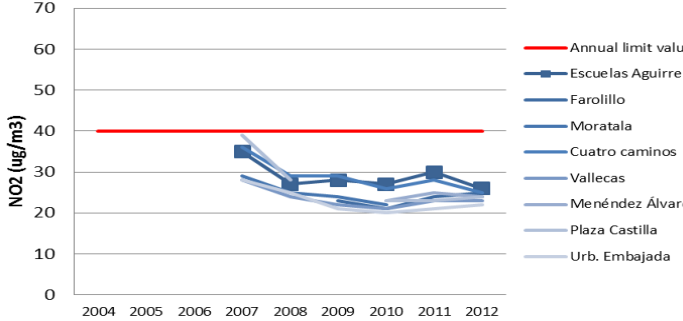
Madrid NO₂ trends; yearly average concentration



Barcelona PM₁₀ trends; yearly average concentration



Madrid PM₁₀ trends; yearly average concentration



Methodology: air quality modelling system



Air quality modelling system:

- Meteorological model (e.g. WRF-ARW)
- Emission model (e.g. HERMES)
- Air quality model (e.g. CMAQ)
- Others: mineral dust model (e.g. NMMB/BSC-Dust), etc.

Configuration:

- High spatial (1x1 km)

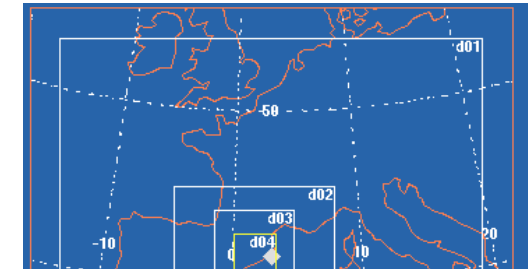


Table 2. Reactions added to CB05 for inorganic sulfur species and their reaction products.

(Source: Mueller et al., 2011)

Reactants	Products	Rate Constant ($\text{cm}^3 \text{ molecule}^{-1} \text{ s}^{-1}$)	Reference
$\text{H}_2\text{S} + \text{OH}$	$\text{SH} + \text{H}_2\text{O}$	$6.0 \times 10^{-12} \exp(-80/T)$	Atkinson et al. (2004)
$\text{H}_2\text{S} + \text{NO}_3$	$\text{SH} + \text{HNO}_3$	1.0×10^{-15}	Atkinson et al. (2004)
$\text{H}_2\text{S} + \text{Cl}$	$\text{SH} + \text{HCl}$	$3.7 \times 10^{-11} \exp(208/T)$	Atkinson et al. (2004)
$\text{SH} + \text{O}$	$\text{SO} + \text{H}$	1.6×10^{-10}	NASA (1997)
$\text{SH} + \text{O}_2$	$\text{SO} + \text{OH}$	4.0×10^{-19}	NASA (1997)
$\text{SH} + \text{O}_3$	$\text{HSO} + \text{O}_2$	$9.5 \times 10^{-12} \exp(-280/T)$	Atkinson et al. (2004)
$\text{SH} + \text{NO}_2$	$\text{HSO} + \text{NO}$	$2.9 \times 10^{-11} \exp(240/T)$	Atkinson et al. (2004)
$\text{SH} + \text{NO} + \text{M}$	$\text{HSNO} + \text{M}$	$k_0 = 2.4 \times 10^{-31} (T/300)^{-3} [\text{M}]$ $k_\infty = 2.7 \times 10^{-11} \text{a}$	Atkinson et al. (2004)
$\text{SH} + \text{Cl}_2$	$\text{ClSH} + \text{Cl}$	$1.7 \times 10^{-11} \exp(690/T)$	NASA (1997)
$\text{HSO} + \text{NO}_2$	$\text{HSO}_2 + \text{NO}$	9.6×10^{-12}	NASA (1997)
$\text{HSO} + \text{O}_2$	$\text{HSO}_2 + \text{O}$	2.0×10^{-17}	Atkinson et al. (2004)
$\text{HSO} + \text{O}_3$	$\text{HSO}_2 + \text{O}_2$	1.1×10^{-13}	Atkinson et al. (2004)
$\text{SO} + \text{OH}$	$\text{SO}_2 + \text{H}$	8.6×10^{-11}	NASA (1997)
$\text{SO} + \text{O}_2$	$\text{SO}_2 + \text{O}$	$1.6 \times 10^{-13} \exp(-2280/T)$	Atkinson et al. (2004)
$\text{SO} + \text{O}_3$	$\text{SO}_2 + \text{O}_2$	$4.5 \times 10^{-12} \exp(-1170/T)$	Atkinson et al. (2004)
$\text{SO} + \text{NO}_2$	$\text{SO}_2 + \text{NO}$	1.4×10^{-11}	Atkinson et al. (2004)
$\text{SO} + \text{ClO}$	$\text{SO}_2 + \text{Cl}$	2.8×10^{-11}	NASA (1997)
$\text{HSO}_2 + \text{O}_2$	$\text{HO}_2 + \text{SO}_2$	3.0×10^{-13}	NASA (1997)



Baldasano et al., 2008; Guevara et al.,

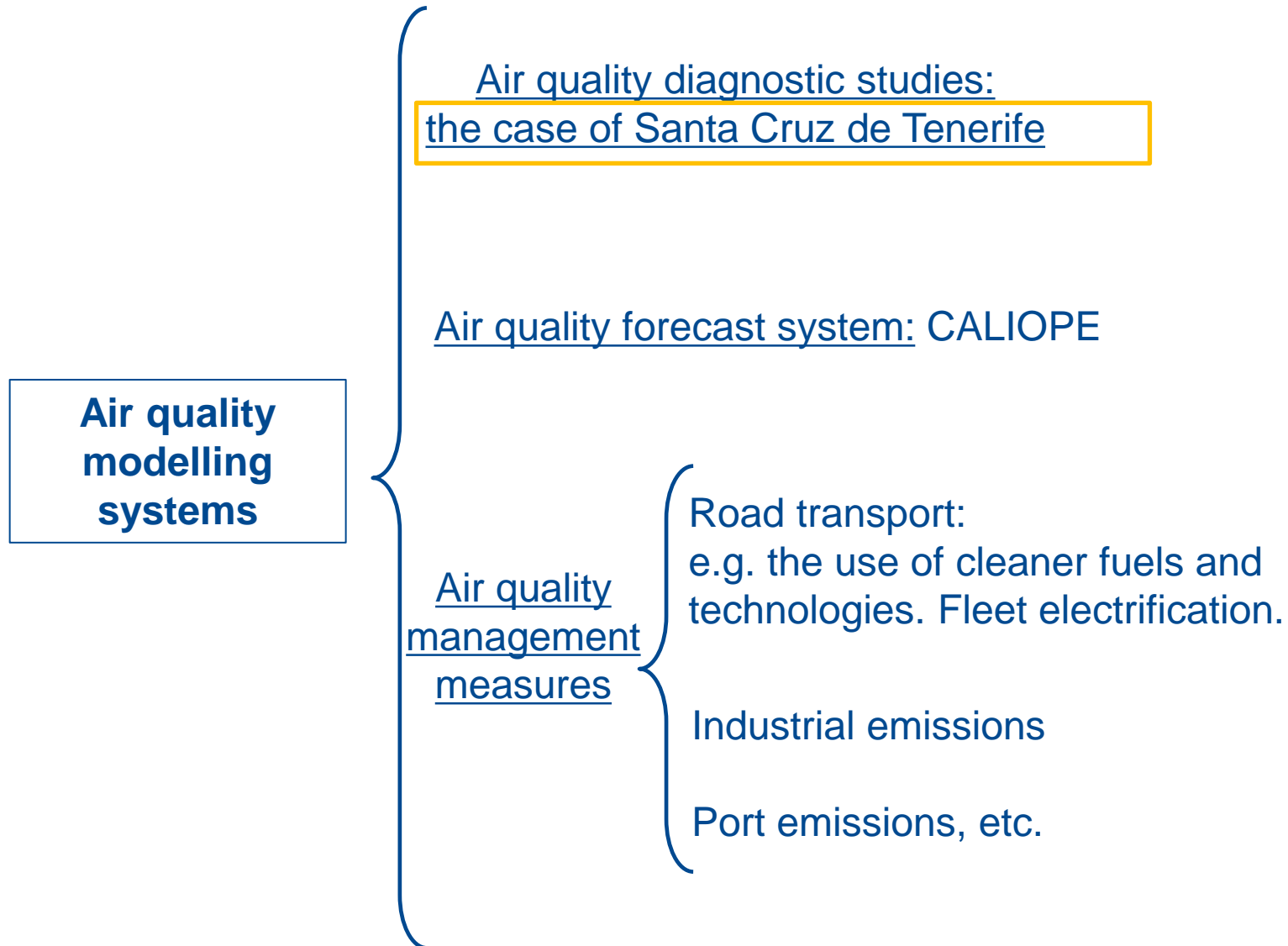
HERMES: Bottom-up emissions

Air quality and climate modelling systems in urban areas. Framework at BSC



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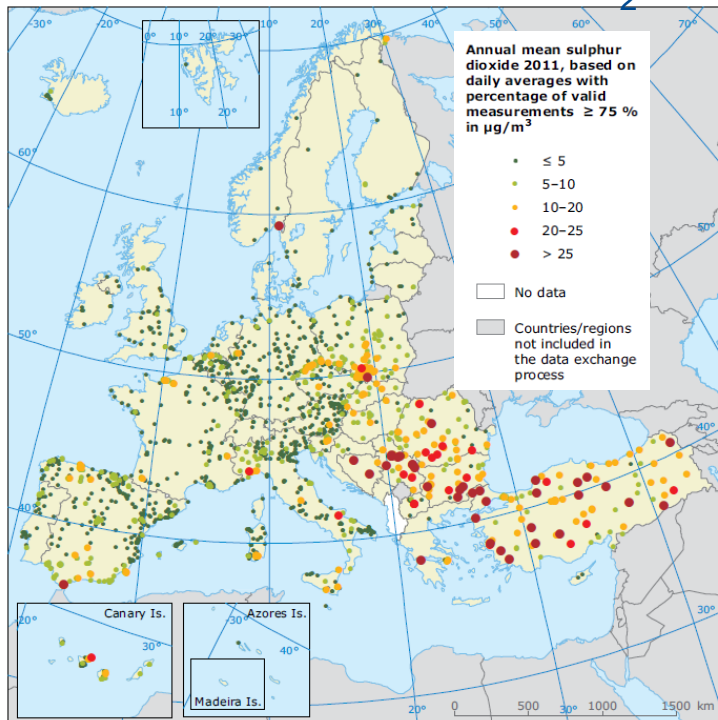
Santa Cruz de Tenerife, atmospheric dynamics



Singular characteristics of Santa Cruz de Tenerife:

- The interaction between the complex topography of the island of Tenerife (3718m) and trade winds.
- Breezes cycles due to the coastal location.
- Thermal inversion at relatively low altitudes that hinders convective motions.

Annual mean concentration of SO_2 in 2011



Dust storm over Canary Islands

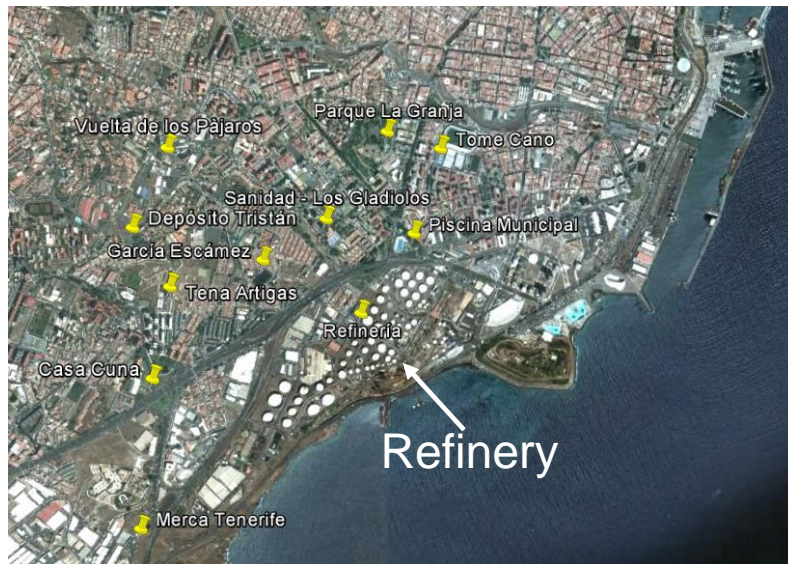


Source: Terra-MODIS

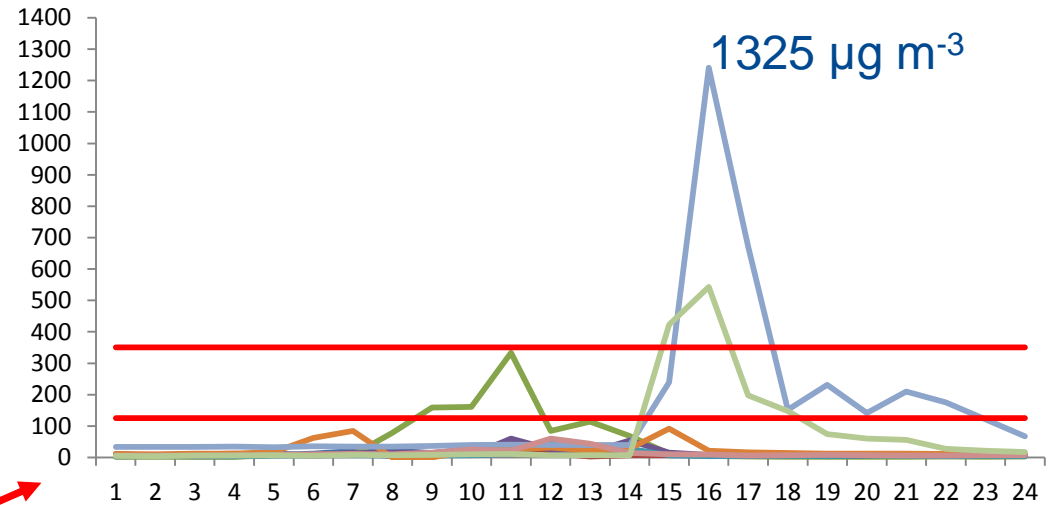
Measured air quality concentration. SO₂.



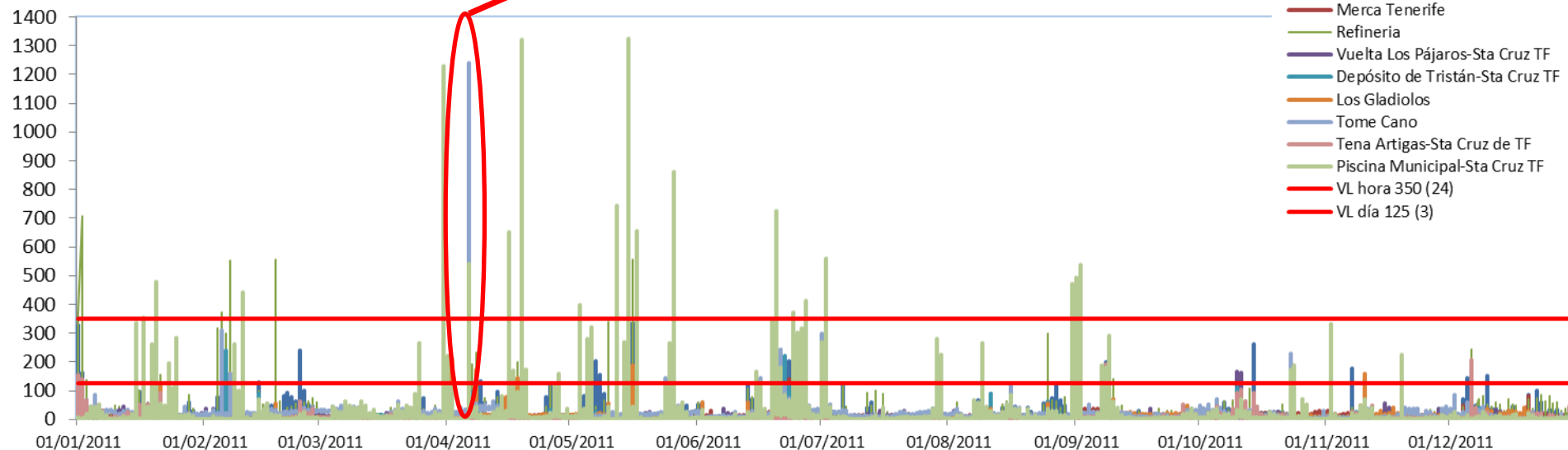
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Hourly SO₂ concentration (ug/m³) April 6, 2011

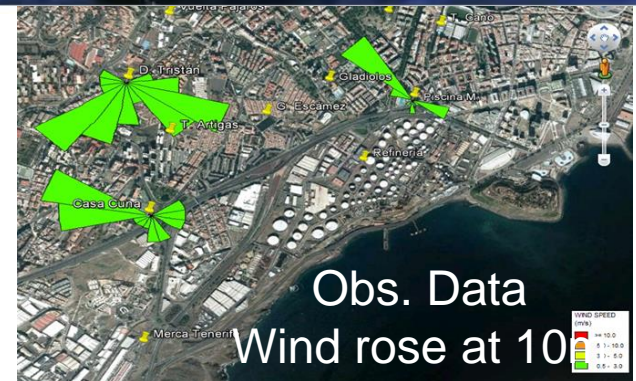


Santa Cruz de Tenerife hourly SO₂ concentration (ug/m³) in 2011



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West (24th January 2011)



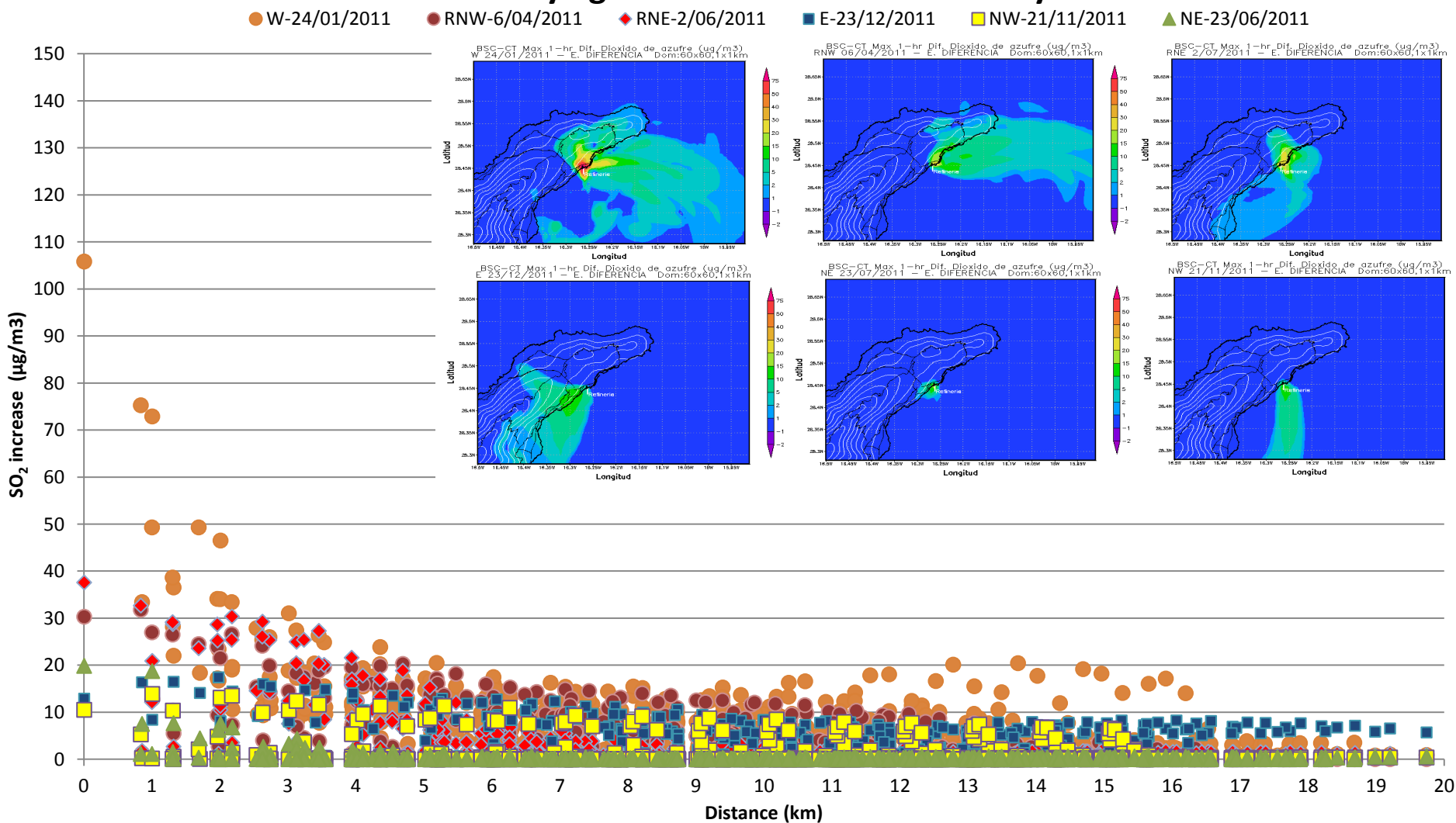
Air quality results. Primary area of influence of the refinery



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Maximum hourly increases of SO₂ due to the emission from the Tenerife refinery against distance to the refinery



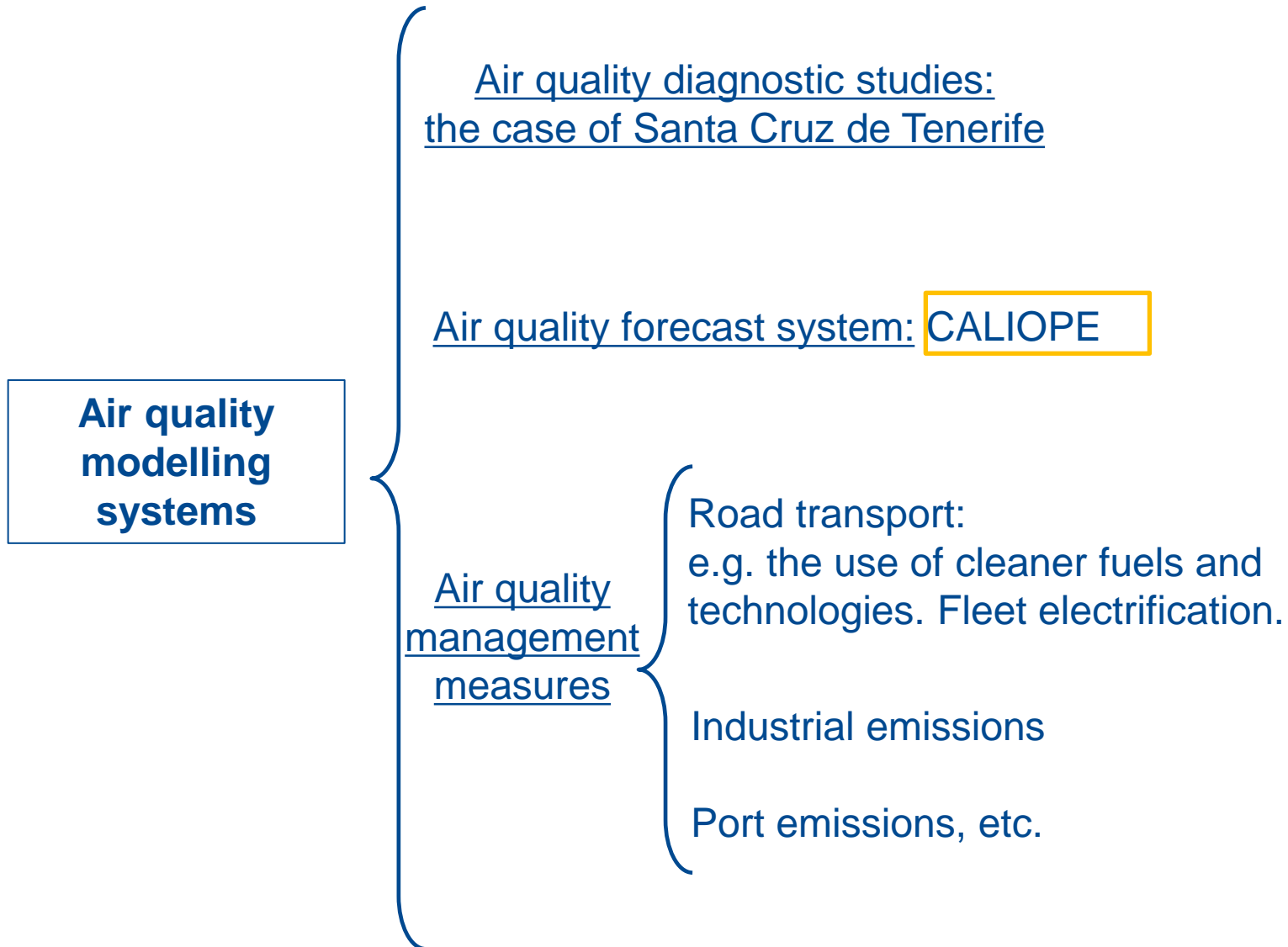
(Baldasano et al., 2014)

Air quality and climate modelling systems in urban areas. Framework at BSC



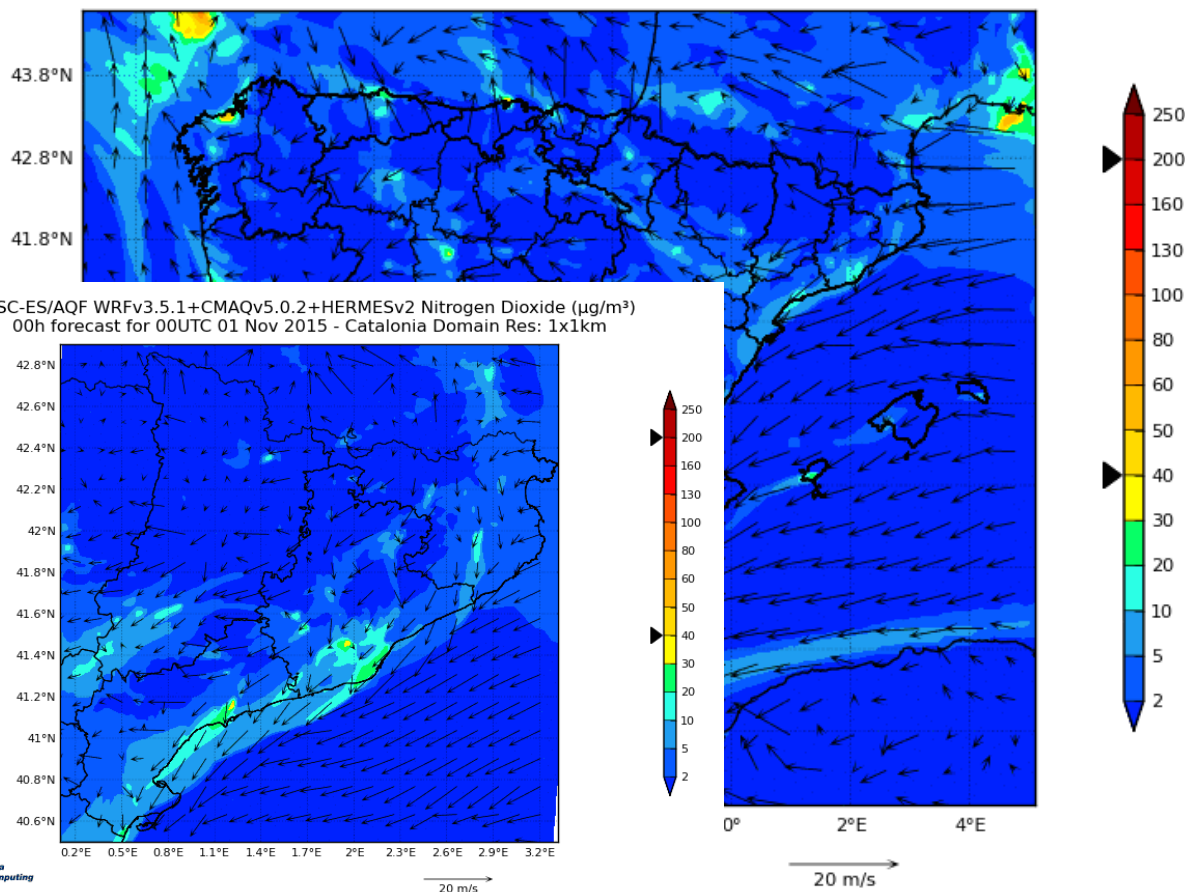
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Provides air quality related information for the coming days and for the application of short term action plans for air quality managers.

BSC-ES/AQF WRFv3.5.1+CMAQv5.0.2+HERMESv2 Nitrogen Dioxide ($\mu\text{g}/\text{m}^3$)
00h forecast for 00UTC 01 Nov 2015 - Iberian Peninsula Res: 4x4km



Information is delivered using both online or custom applications:

www.bsc.es/caliope

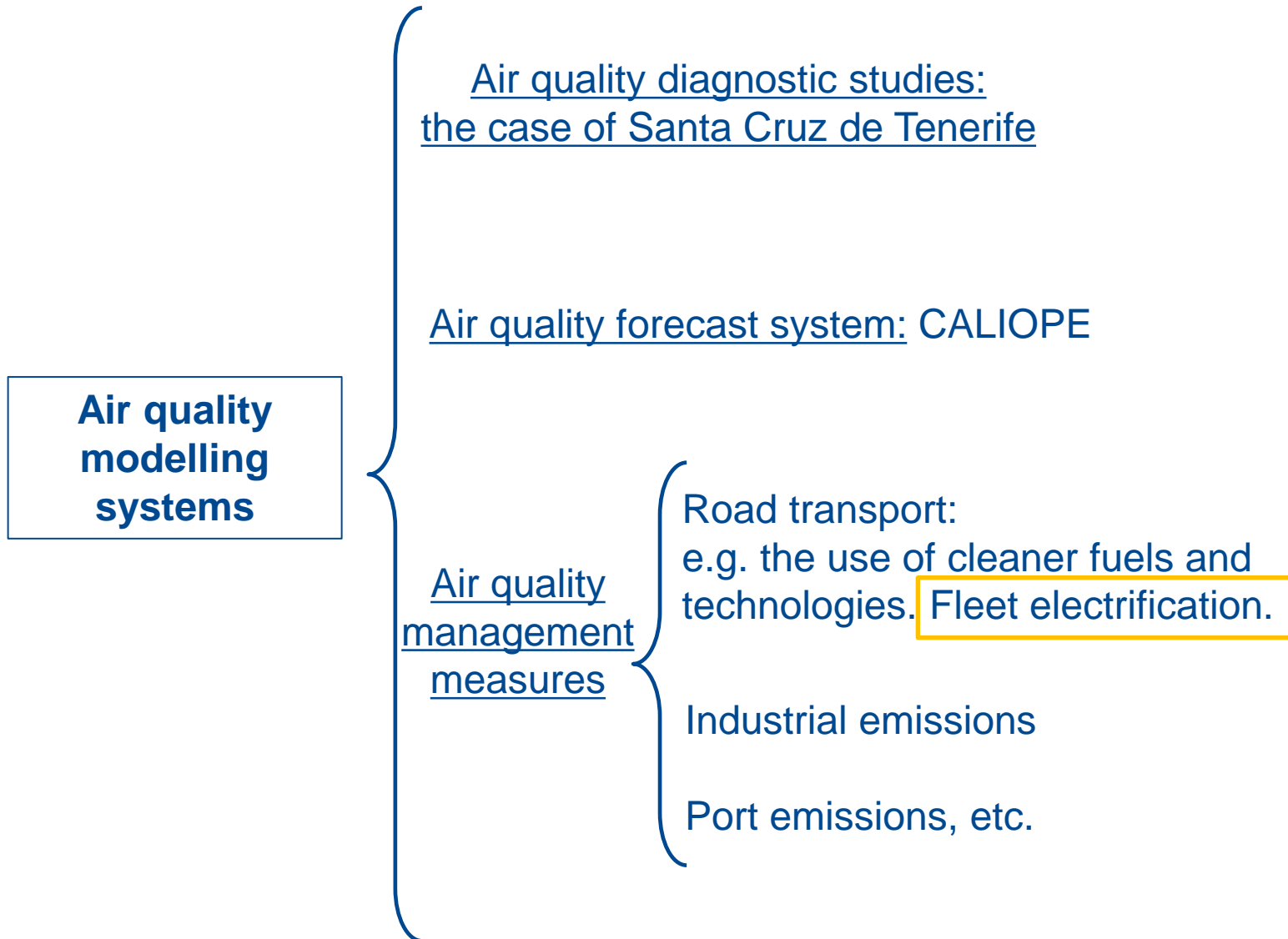


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Fleet electrification: Replacement of internal combustion vehicles by electric vehicles

	Fuel red.	Autonomy	
Micro-hybrid	5-10%		
Mild-hybrid	10-20%		
Full-Hybrid (HEV)	20-30%	2 km	
PHEV	35-85%	20-80 km	
Range Extender	65-100%	50-120 km	
BEV	100%	80-300 km	
Fuel cell vehicle (FCEV)	H2	400-600 km	

Hybrid electric vehicles (HEV)



e.g. Van Hool Exquicity

Plug-in electric vehicle (PHEV)



e.g. Piaggio MP3 Hybrid 300

Battery electric vehicle (BEV)



e.g. BMW i3

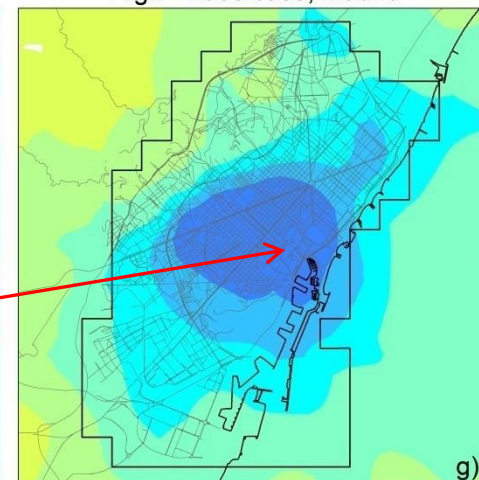
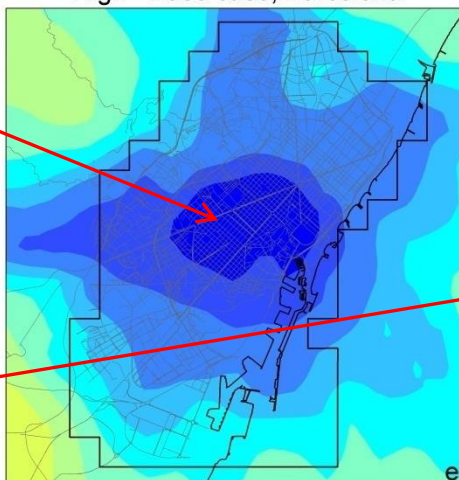
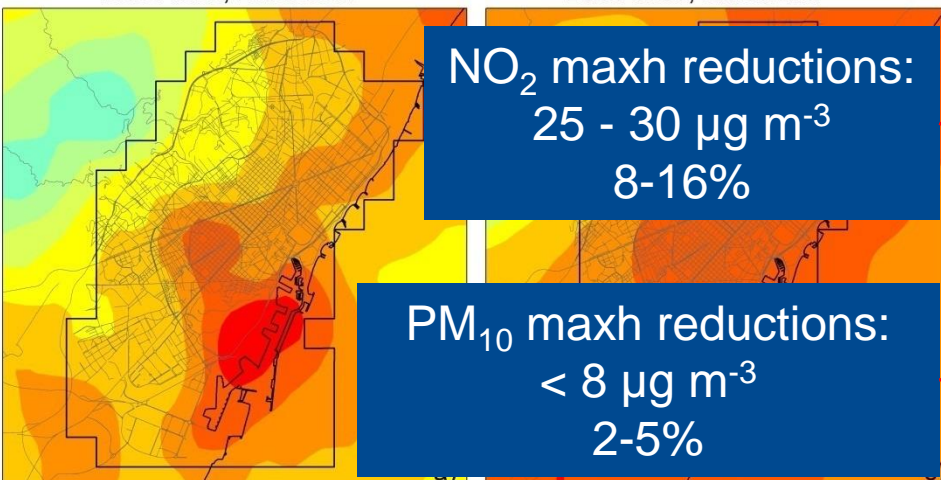
Fleet electrification. Air quality impacts

NO₂ (ug m⁻³) Max h
Base case; Barcelona

PM₁₀ (ug m⁻³) Max h
Base case; Barcelona

NO₂ (ug m⁻³) Max diff h
High - Base case; Barcelona

PM₁₀ (ug m⁻³) Max diff h
High - Base case; Madrid

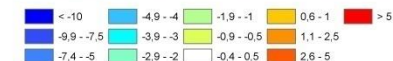
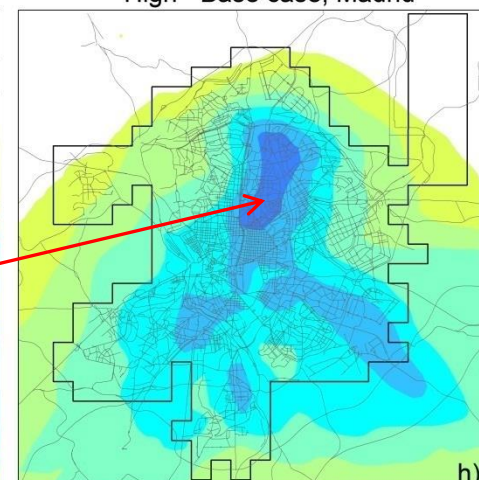
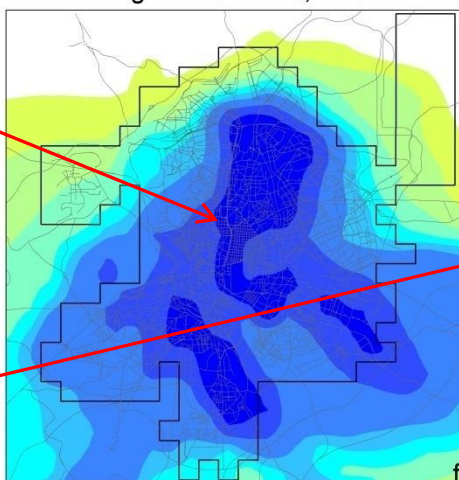
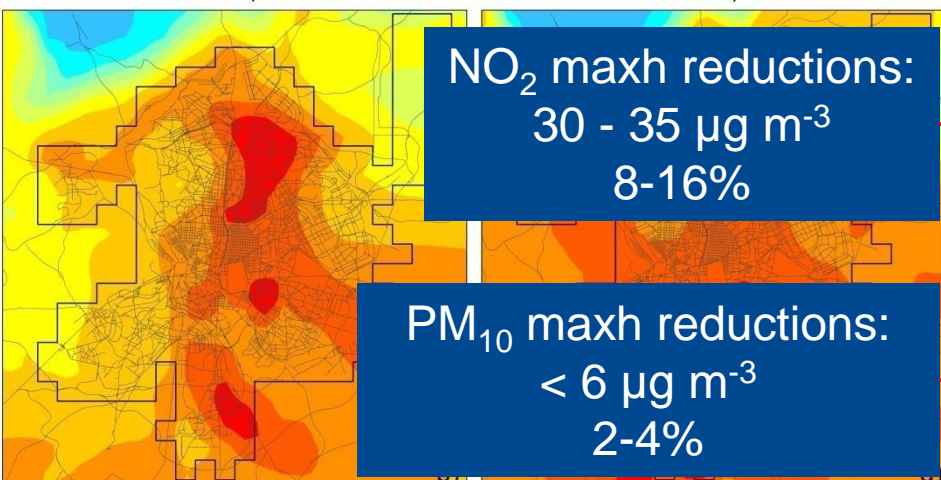


NO₂ (ug m⁻³) Max h
Base case; Madrid

PM₁₀ (ug m⁻³) Max h
Base case; Madrid

NO₂ (ug m⁻³) Max diff h
High - Base case; Madrid

PM₁₀ (ug m⁻³) Max diff h
High - Base case; Madrid



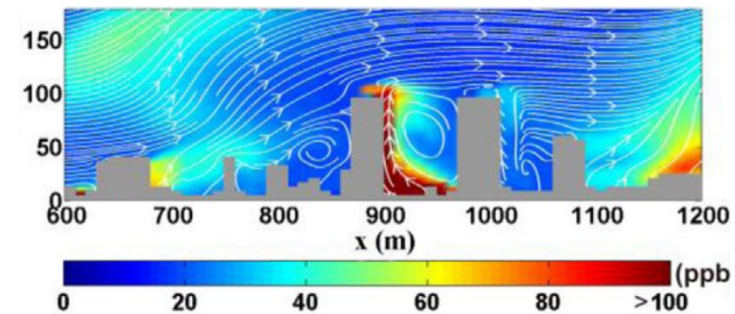
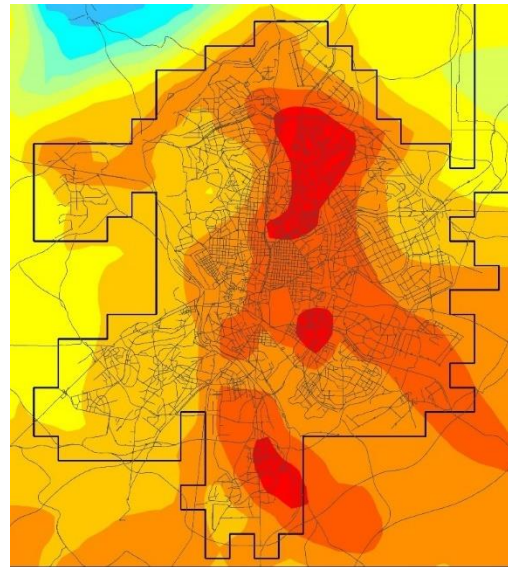
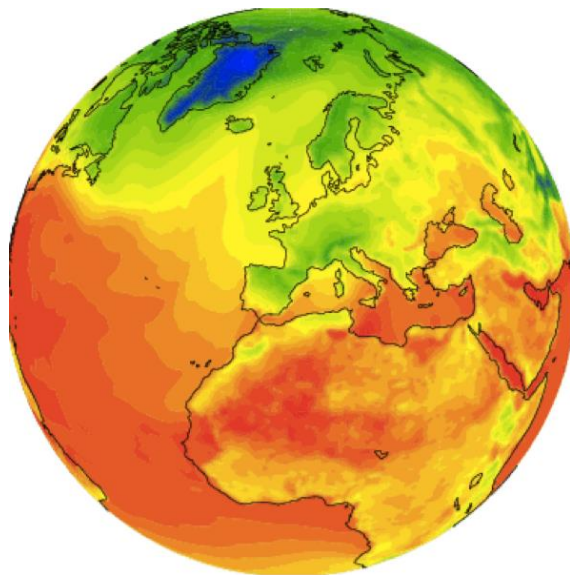


Future work

Further understanding of urban processes.

Further understanding of local scales processes to allow the assessment of sustainable management of urban areas within the SmartCities context by using two key-elements:

- microscale atmospheric models
- observations from smart infrastructures



From global to regional scales

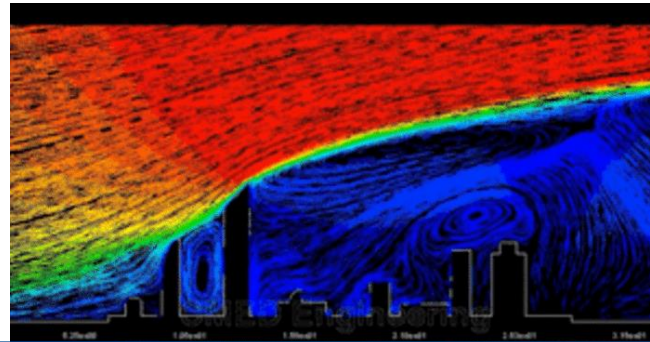
Next step: microscale

Air quality assessment at urban scales.

Strategy: interdisciplinary approach



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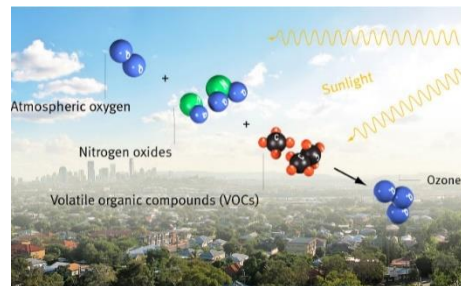
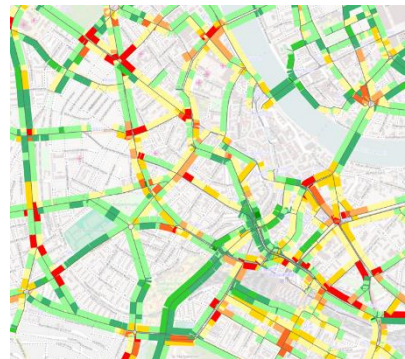
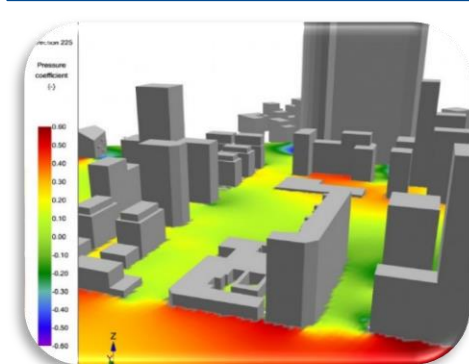
Proof of concept: modelling tool to monitor and forecast air urban quality (Smart Cities applications)

Meteorological
core

Emission
module

Air quality
module

Smart
infrastructures



CASE dep. + Earth Sciences dep. + Computer dep.

National and International collaborations



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Research centers



Local administrations and international organizations



Meteorological offices



National and International collaborations



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Industrial partners. Air quality

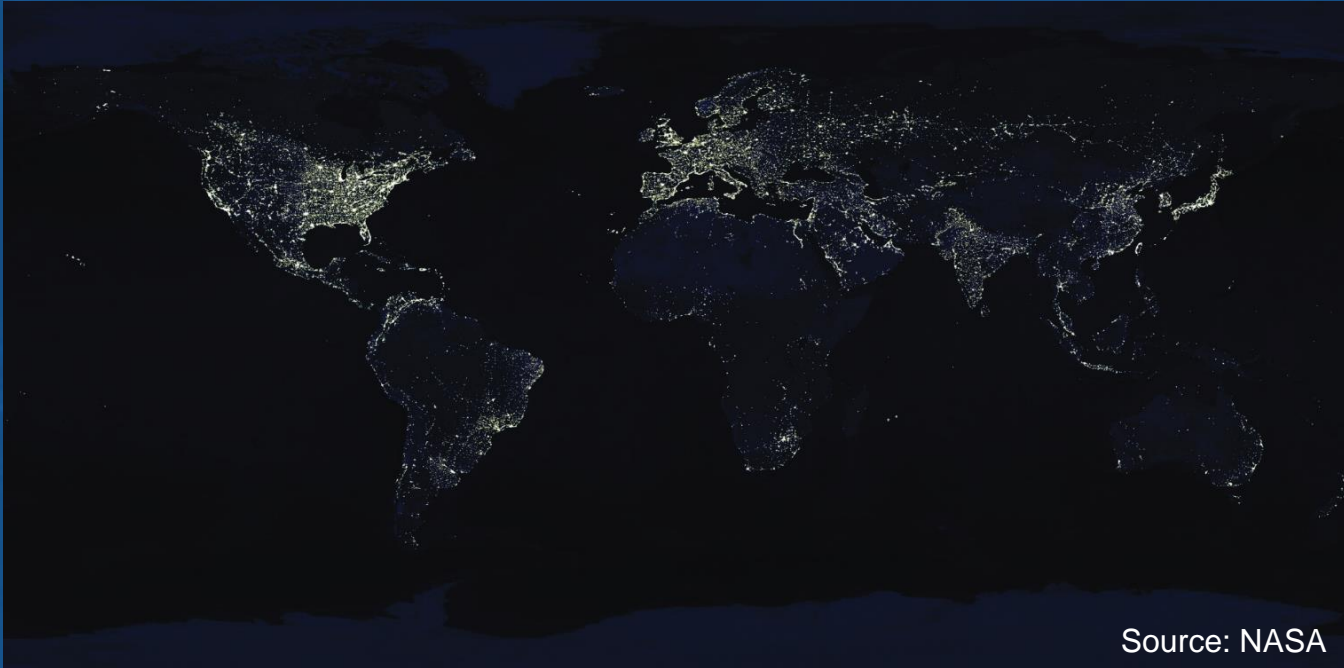


Industrial partners. Energy



Industrial partners. Agriculture





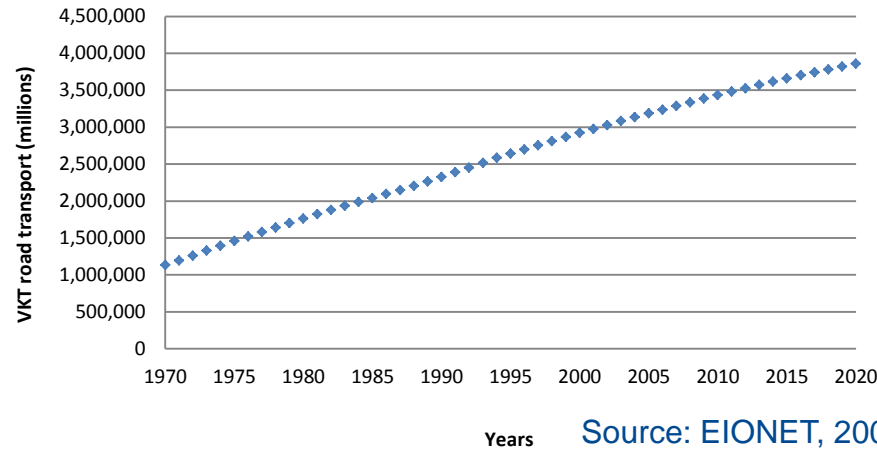
Source: NASA

Satellite view of Earth at night. 1-4% of land surface is urban.
More than 50% of world's population lives in urban areas.

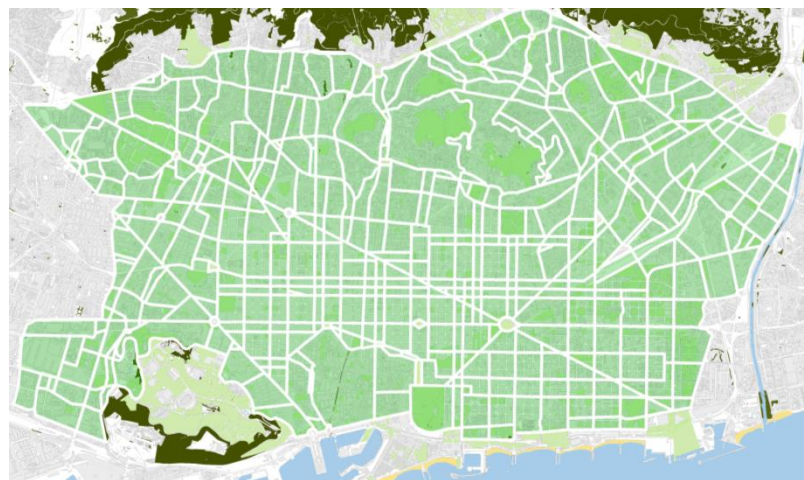
Thank you!

For further information please contact
albert.soret@bsc.es

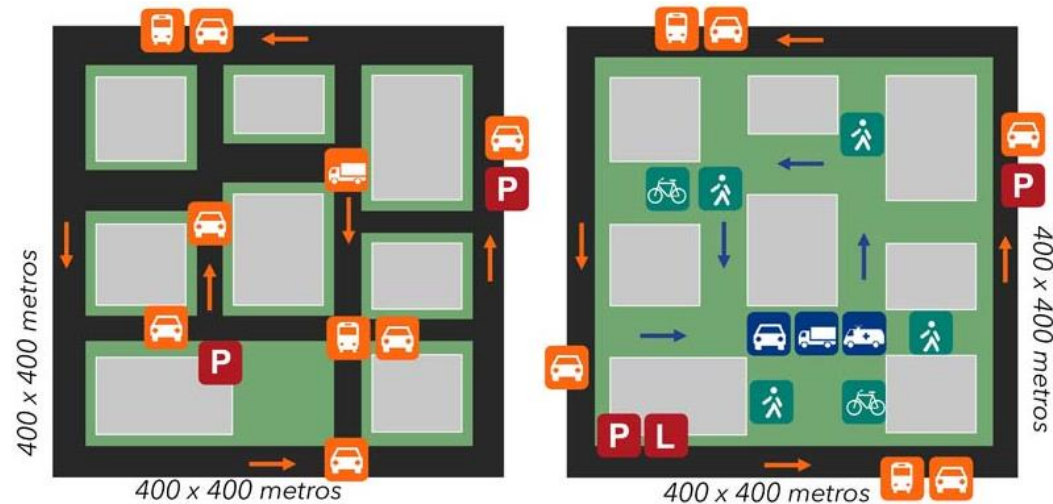
Traffic growth in Europe



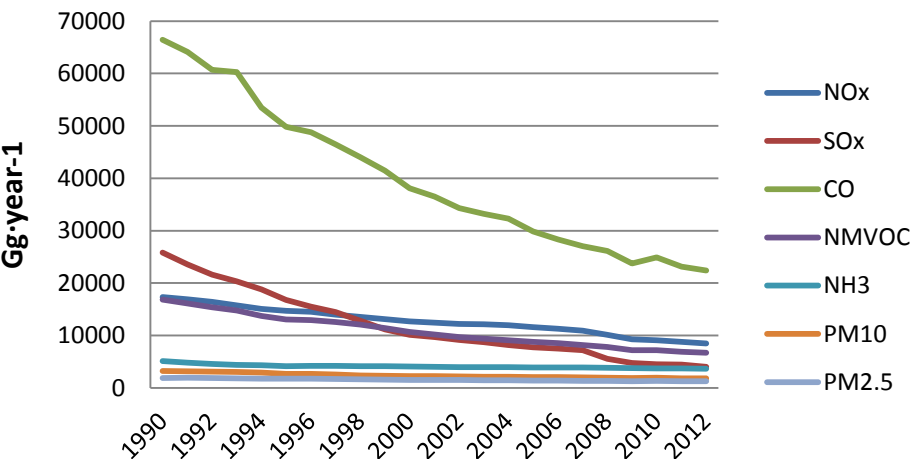
Implementation of Superblocks in Barcelona



Source: BCNEcologia

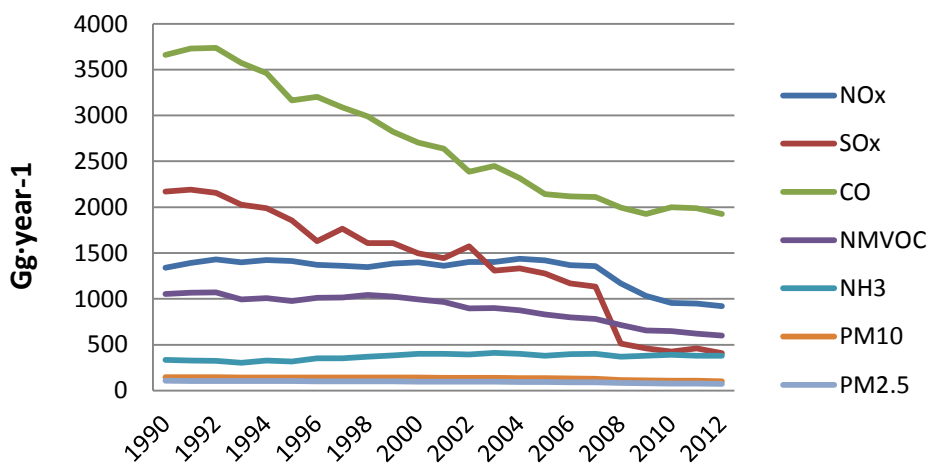


Emission trends in Europe (EU-28)



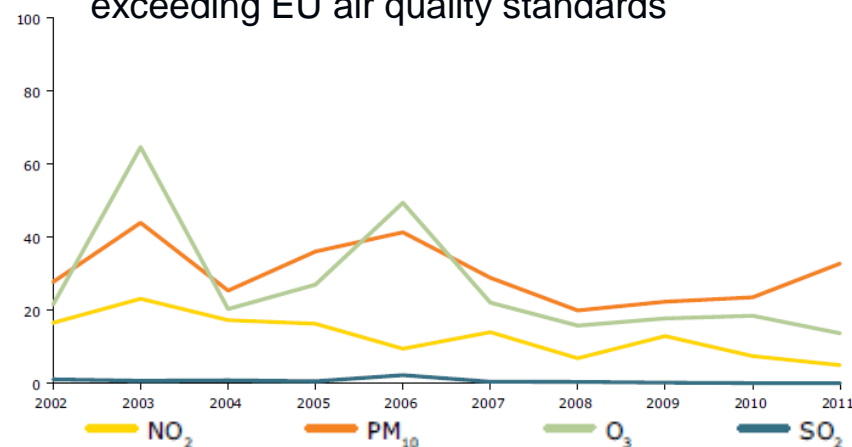
Emission have dropped considerably but
air quality still needs to improve

Emission trends in Spain



A significant proportion of urban
population is exposed to air quality
concentrations exceeding EU air
quality standards

% of urban population exposed to air pollution
exceeding EU air quality standards



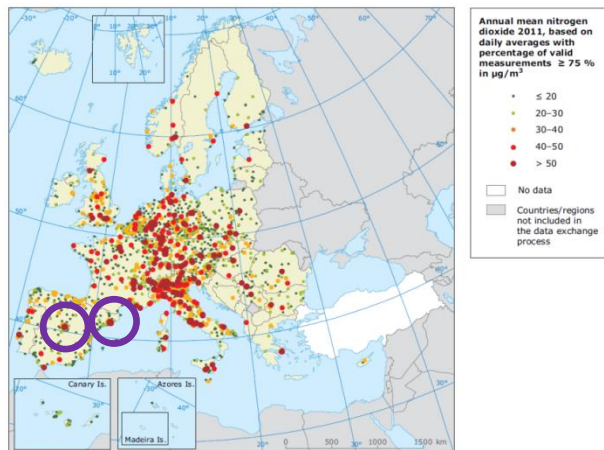
Source: EEA, 2013

Air quality in Europe

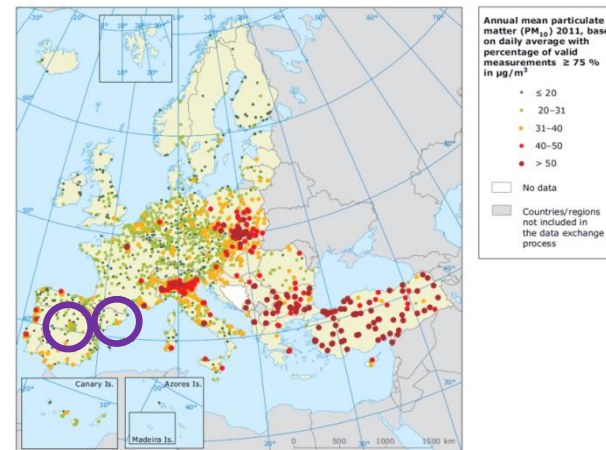
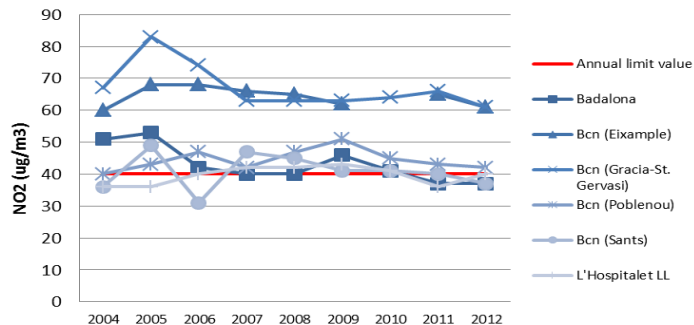


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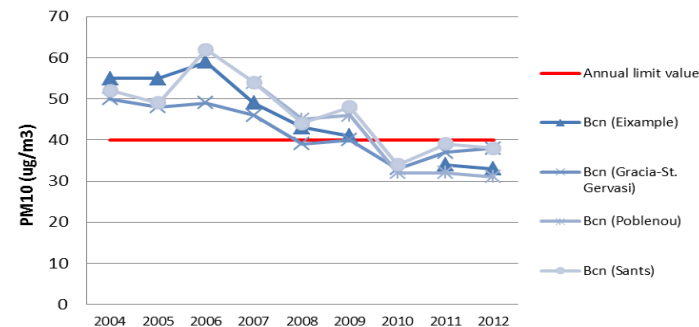
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SEVERO
OCHOA



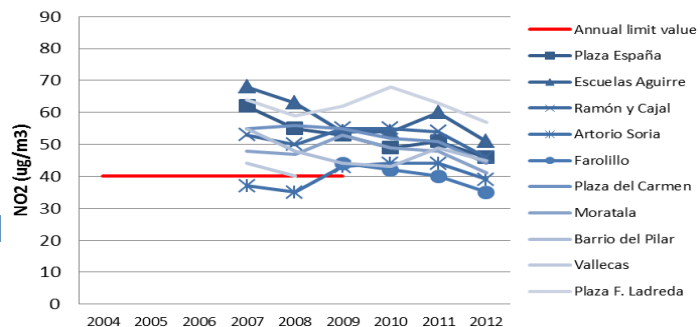
Barcelona NO_2 trends; yearly average concentration



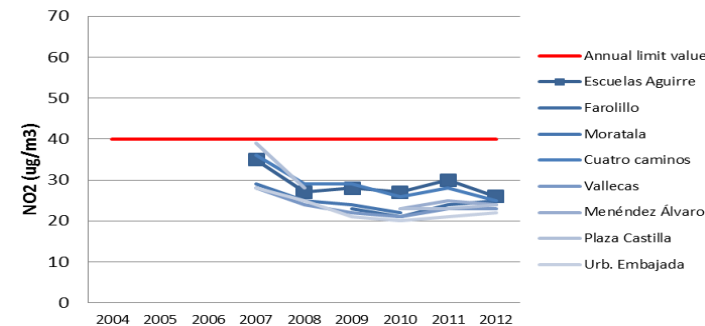
Barcelona PM_{10} trends; yearly average concentration



Madrid NO_2 trends; yearly average concentration



Madrid PM_{10} trends; yearly average concentration



Year 2011
EEA, 2013

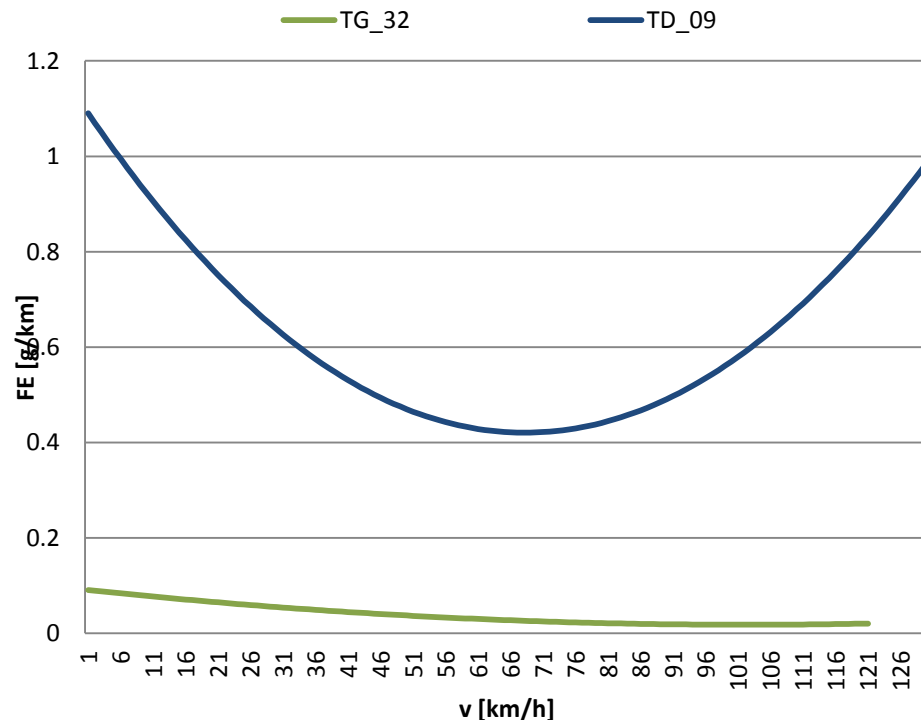
Emission factors. Diesel and gasoline



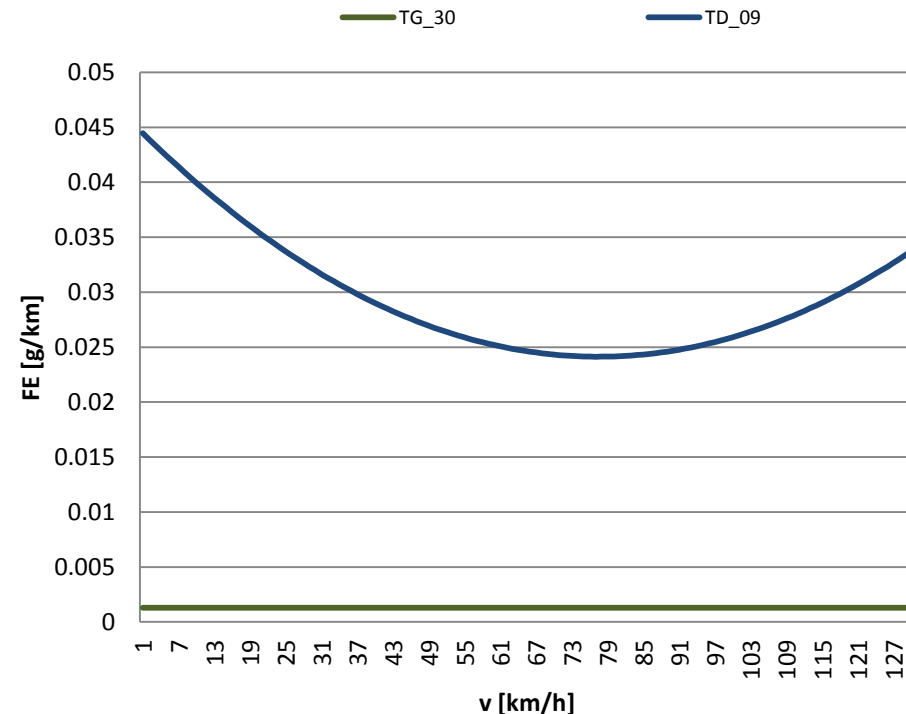
The Mayor of Paris has announced radical plans to ban diesel cars from the French capital by 2020 due to concerns about how much pollution the cars cause (France has the highest number of diesel cars in Europe). And the Mayor of London is also considering similar solutions.

She also said that the city would have more semi-pedestrianised areas with special zones introduced at weekends.

NOx PC Gasoline and Diesel

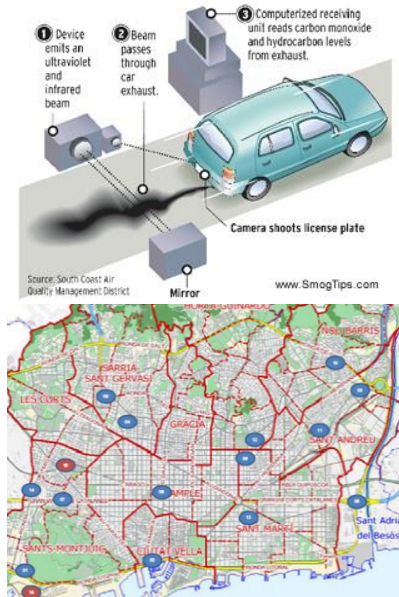


PM- PC Gasoline and Diesel



Improvements for the road transport emissions

Remote Sensing Device



	RSD [g/km]	COPERT [g/km]	RSD/COPERT [%]
NO _x	1,172	1,005	+16,6%
PM ₁₀	0,124	0,070 (*)	+75,5%

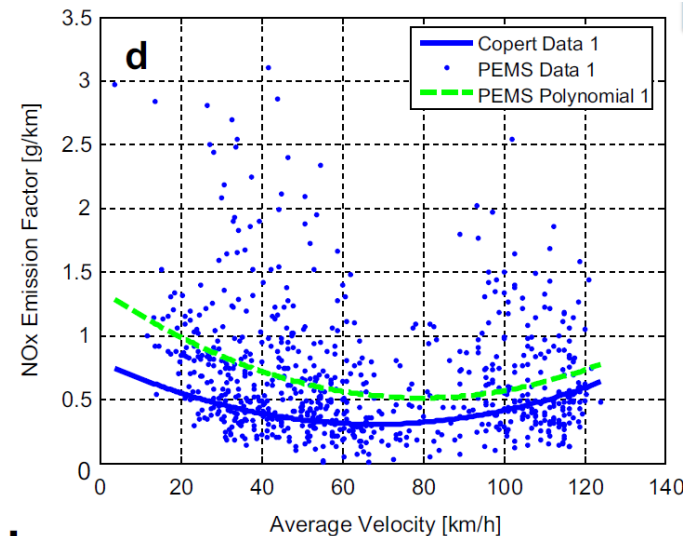
AB (2010)

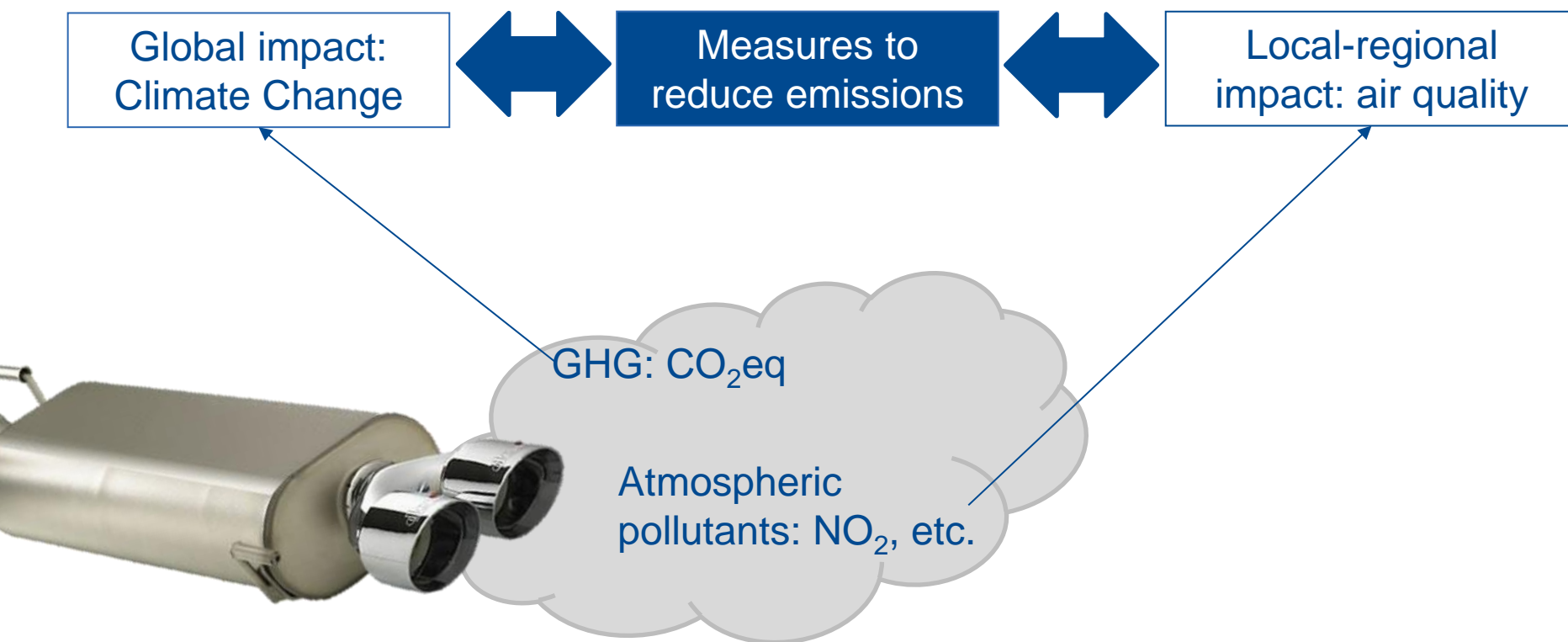
Portable Emission Measurement System



Kouridis et al. (2013)

EF NO_x - Euro 5 diesel PC

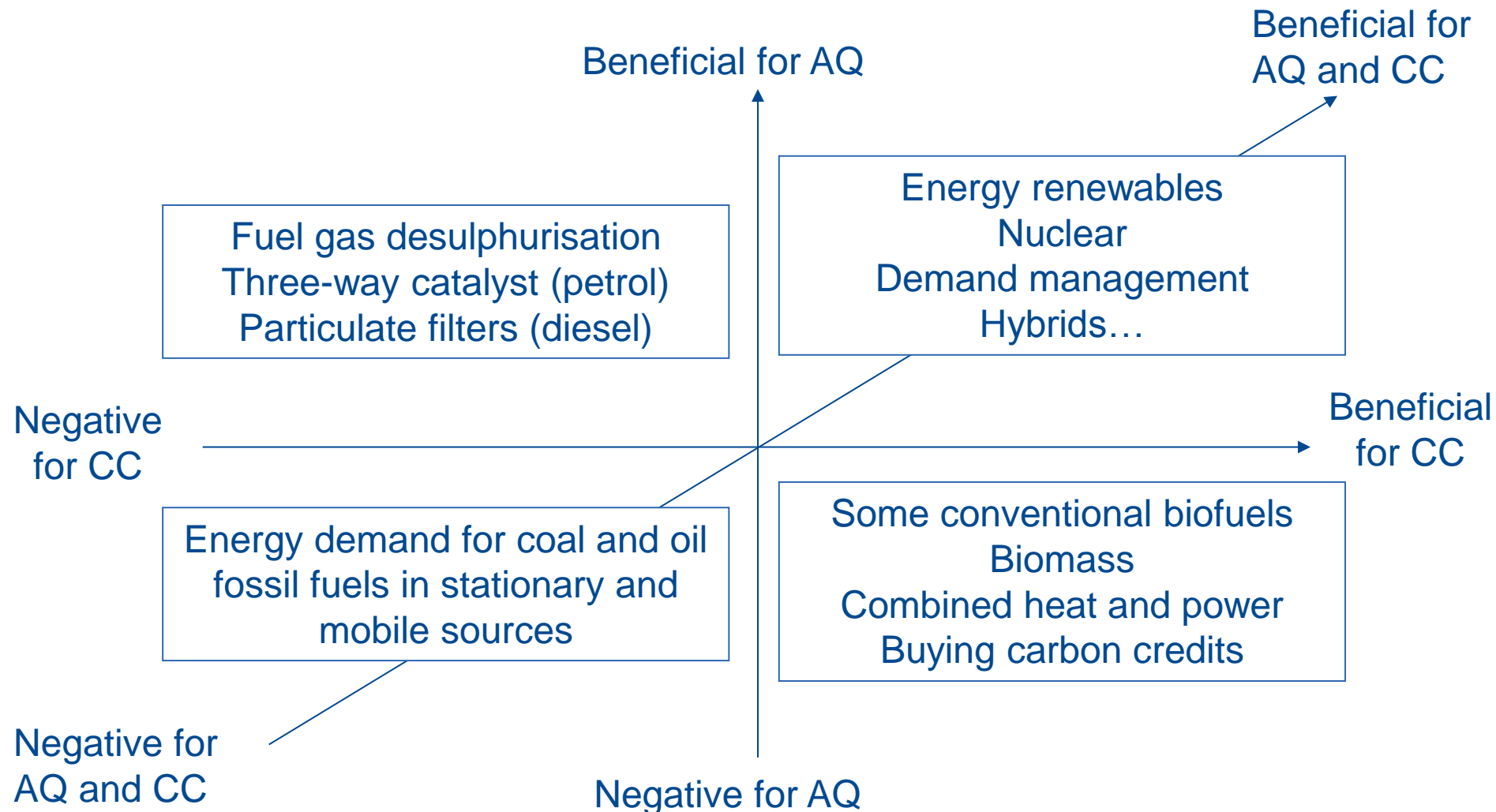




Air quality and climate change. Measures to reduce emissions



Air quality (AQ) and climate change (CC) synergies and trade-offs

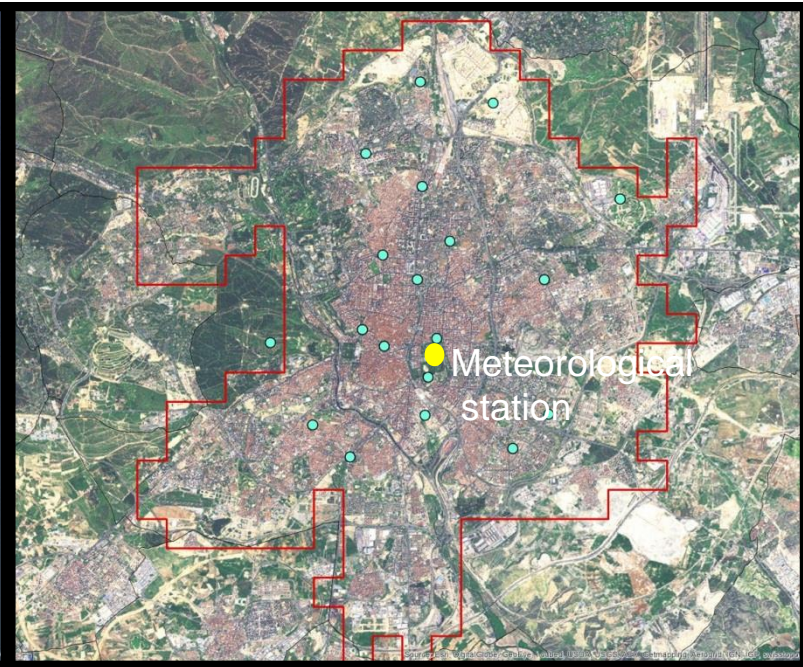
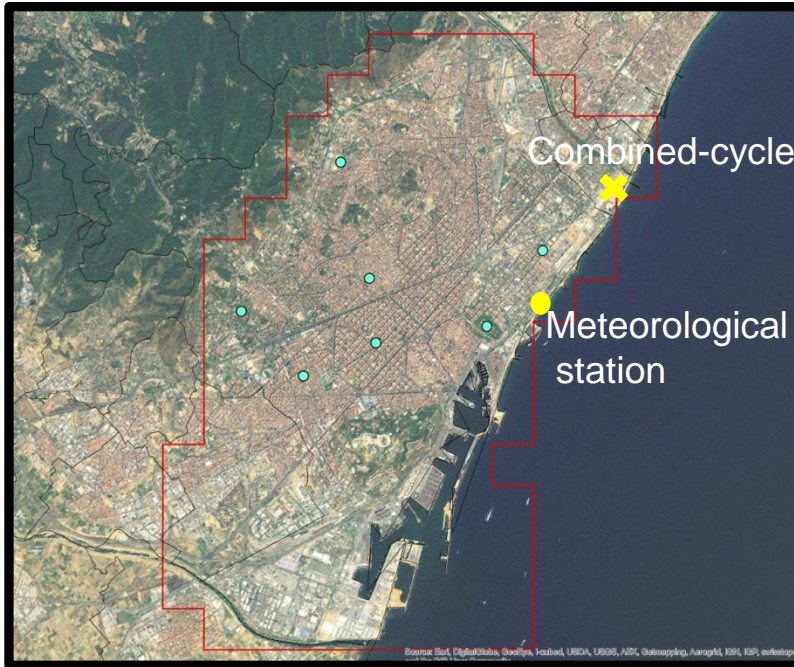


Areas of study: Barcelona and Madrid

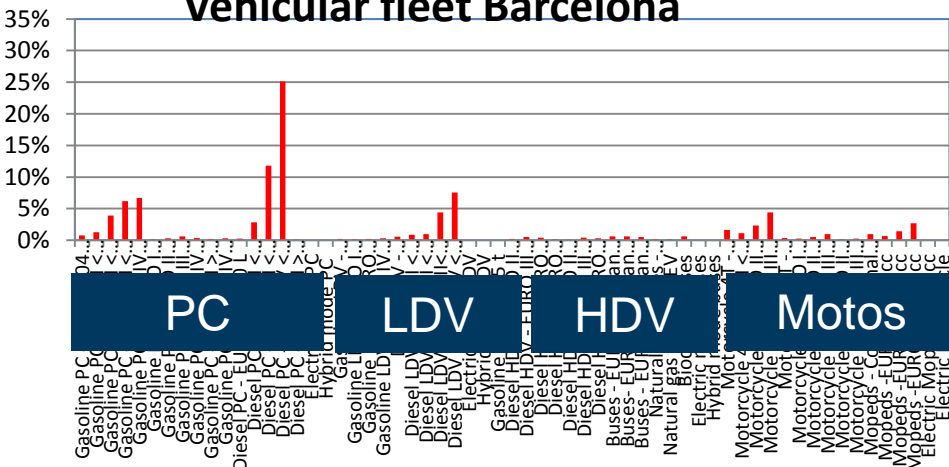


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